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(54) APPARATUS FOR GENERATING HEAT

(71) We, FOSTER WHEELER ENERGY CORPORATION, a corporation organised and existing under the laws of the State of Delaware, United States of America, of 110 South Orange Avenue, Livingston, New Jersey 07039, United States of America, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to an apparatus and method for generating heat and, more particularly, to such an apparatus and method in which sulphur present in the effluent gases and therefore the amount of air pollution, is substantially reduced.

The use of fluidized beds has long been recognized as an advantageous way of generating heat, such as in the use of heat exchangers or the like in which steam is generated from water passing in a heat exchange relation to the fluidized beds. The bed usually includes particulate fuel, such as coal, and is fluidized by passing air through the fuel to promote the combustion thereof. The advantages of this type of arrangement include an improved heat transfer rate, a reduction in corrosion, a reduction in boiler fouling, an increase in combustion efficiency, a lower combustion temperature and a reduction in boiler size.

In U.K. Patent Specification No. 1,427,166, a vapour generator is disclosed in which a plurality of fluidized beds are arranged in a stacked manner which enables a relatively large range of heat transfer to be obtained, yet otherwise enjoys the other advantages of the fluidized beds set forth above.

In some of the prior art arrangements mentioned above, as well as in the above-mentioned application, the material in the bed that is fluidized consists of a mixture of sorbent, or sulphur accepting material, such as limestone or dolomite, and a particulate fuel, such as coal, with the sorbent acting to absorb the sulphur released during combustion of the fuel in the beds for the purpose of minimizing the polluting effect of the sulphur. The sulphated sorbent thus formed is passed to an external sorbent regenerator in which it is regenerated, or desulphated, after which the sulphur recovered is collected, or treated further while the regenerated sorbent is passed back into the fluidized beds for further use.

Although these type arrangements are successful in reducing the polluting effect of the sulphur the provision of a separate sorbent regenerator located externally of the main heat exchanger is relatively expensive and considerably adds to the costs of the overall system.

Also, many of the above-mentioned regenerators used to recover the sulphur used natural gas, or some other relatively expensive reducing agent, which further adds to the cost of the system.

It is an advantage of this invention that there is provided a heat generating apparatus and method in which the necessity of a separate sorbent regenerator is eliminated, yet which enables the sulphur to be separately recovered.

It is a further advantage of a preferred aspect of this invention that there is provided an apparatus and method of the above type in which the sorbent material is desulphated in an additional fluidized bed disposed in the main heat exchanger housing adjacent the other fluidized beds.

It is still a further advantage of a preferred aspect of the present invention that there is provided an apparatus and method in which the sulphur is recovered by contacting the sulphur enriched gas formed in the above additional fluidized bed with a relatively inexpensive, granular, high-sulphur coal.

According to the invention there is provided an apparatus for generating heat comprising means defining at elast one first zone for combusting a fuel in the presence of a sorbent for sulphur released during combustion of the fuel at conditions sufficient to sulphate the sorbent, means defining a second zone for receiving at least a portion of the sulphated sorbent from the first zone or zones and for combusting a fuel under conditions in which the sorbent is desulphated to form a sulphur enriched gas, means for transferring sulphated sorbent from the first zone to second zone, means for receiving the gas and continuously contacting the gas with burning granular coal to reduce at least a portion of the gas to sulphur, and means for transferring the gas from the second zone to the means for contacting the gas with burning coal.

Also according to the invention there is provided a method of burning sulphur containing fuels, comprising burning a sulphur containing fuel in at least one first combustion zone in association with a sorbent for the sulphur contained in the fuel at conditions whereby sulphur compounds produced in the combustion process react with the sorbent to sulphate the sorbent, removing at least a portion of the sulphated sorbent from the first combustion zone or zones and passing the sulphated sorbent into a second combustion zone, and burning fuel in the second combustion zone at conditions sufficient to desulphate the sorbent and form a sulphur enriched gas, removing the sulphur enriched gas from the second combustion zone, and contacting the sulphur enriched gas with burning granular coal to reduce at least a portion of the gas to sulphur.

The invention will be further described by way of example and with reference to the accompanying drawing which shows a partial schematic, partial sectional, view depicting an embodiment of an apparatus according to the present invention.

The drawing shows a vapour generator incorporating features of the present invention and including a housing 10 having several openings for the passage of air therethrough and for receiving pipes as will be described in detail later. An enclosure 12 is defined within the housing and comprises a front wall 14 and a rear wall 16 shown in cross section, with each wall being formed by a plurality of finned tubes welded together in a conventional manner and extending for the entire length of the wall. A pair of side walls are also provided but are not shown in the drawings for the convenience of presentation.

A plurality of air distribution plates 20 are disposed in a spaced relationship in the enclosure 12 to divide the enclosure into a plurality of vertically stacked chambers, or compartments. Since the five upper compartments are identical, they are each referred to by the reference numeral 22. The lowermost compartment is slightly different from the compartments 22 and is referred to by the reference numeral 24.

A mixture of particulate sulphur-containing fuel and a non-combustible, sulphur accepting material, or sorbent, is injected into each compartment 22 via a feed line 26 extending through suitable openings provided in the housing 10 and the wall 16, and passing through the distributor plate 20 associated with each compartment 22, the lines 26 are adapted to receive the particulate fuel and sorbent from a source, such as a pneumatic feeder, which has not been shown in the drawing for the sake of simplicity.

The fuel material is preferably in the form of a fossil fuel, such as high sulphur bituminous coal, while the particulate sorbent material is preferably in the form of limestone or dolomite.

Air from an external source is passed into the housing 10 via an inlet 30 and is passed in a direction shown by the dashed arrows to the area defined between the front wall 14 of the enclosure 12 and the corresponding wall of the housing 10, whereby it splits into individual streams which pass through a damper 32 into an air plenum chamber 34 extending below each distribution plate.

As a result, the bed of mixed particulate material in each compartment 22 is fluidized and the fuel continuously combusts after being ignited, with the velocity and rate of flow of the air passing through the beds being regulated so that it is high enough to fluidize the particulate fuel and to obtain economical burning or heat release rate per unit of area bed, yet is low enough to avoid the loss of too many fine fuel particles from the bed and to allow sufficient residence time of gases for sulphur removal by the sorbent material.

The temperature of the fluidized beds in the compratments 22 is regulated so that the particulate fuel combusts and the sorbent material sulphates, which in the case of limestone, would consist of a calcinizing of the limestone and a reaction of the latter with the sulphur oxides from the combusted fuel to produce a calcium sulphate. A satisfactory temperature to achieve the above would be 1600° ± 150°F.

The combustion gases, which include the air passing through the fluidized beds, as well as fine particles of unburned fuel material, fly ash and sulphated sorbent, discharge through outlets 36 provided in the rear wall 16, as shown by the dashed arrows, and flow into a manifold duct 38 disposed to the rear of the wall 16 and extending for substantially the entire length thereof. The gases are then directed from the duct 38, through a duct 40 and to a cyclone type dust collector 42 which removes a great majority of the fine particles of unburned fuel material, fly ash and sulphated sorbent from the gases. The gases with the fine particles thus removed may then be passed from the dust collector 42 directly to atmosphere through a stack, or, alternatively to a secondary solids removal device, an air heater, or the like for further treatment before being passed to atmosphere. In either case, the gases are substantially sulphur free and therefore cause minimal air pollution.

After being separated out of the stream of gases by the dust collector 42, the abovementioned fine particles are directed to a dust hopper 44 and then into an injector 46 which injects the particles back into the compartment 24 through lines 48. The compartment 24 is also directly supplied with the mixture of particulate fuel and sulphated sorbent from each of the beds in the compartments 22 via a plurality of pipes 50 extending from the latter compartments, and a distribution pipe 52 connected to the pipes 50 and discharging in the particulate bed disposed in the compartment 24. Although not shown in the drawing, if necessary, a separate supply of particulate fuel can be supplied to the compartment 24.

The materials in the compartment 24 are fluidized by air passing into this compartment through a damper 32 and an air plenum chamber 34 associated therewith, in a manner similar to that described in connection with the materials in the compartments 22. The temperature in the compartment 24 is maintained at a relatively high value, such as 2000° ±200°F., so that the sulphated sorbent material, which if in the form of calcium sulphate, for example, is decomposed, or desulphated, to release the sulphur dioxides and regenerate the calcium oxide in accordance with the following reaction:

$$CaSO_4 + \begin{pmatrix} CO \\ H_2 \end{pmatrix} \longrightarrow CaO + SO_2 + \begin{pmatrix} CO_2 \\ H_2O \end{pmatrix}$$

The sulphur dioxide enriched gas thus generated leaves the compartment 24 through its outlet 36 and into a duct 54 whereby it is directed to a separate cyclone 56 for removal of any fine particulate material therefrom, before being passed to a duct 58 for further processing in which it is converted to sulphur and/or hydrogen sulphide in a manner to be described in detail later.

The regenerated sorbent, or calcium oxide, formed in the compartment 24 is passed, via a pipe 60, to a vertical distributor pipe 62 and, from the vertical distributor pipe 62 through a plurality of individual pipes 64 into each fluidized bed disposed in the compartments 22. As a result, the calcium oxide can again be utilized to absorb the sulphur from the combustion gases in each bed, as described above.

The above transfers of material to and from the various beds can be done in a conventional manner, such as by pneumatic injection, etc., using standard equipment such as overflow pipes with level controls, etc.

The sulphur enriched gas from separator 56, which in the example described is in the form of sulphur dioxide, is passed to the duct 58 for further treatment. The duct 58 discharges into a reactor vessel 70 formed with an upper inlet 72 which is connected in flow communication with a granular coal hopper 74. A valve 76 is disposed in the inlet 72 and controls the flow of coal from the hopper 74 to the vessel 70. An outlet 78 is disposed at the lower end of the vessel 70 and communicates the lower end of the vessel with an ash product trough 80, a valve 82 controlling the flow of ash from the vessel to the trough. The reactor vessel 70 operates to burn the coal from the hopper 74 while maintaining a predetermined minimum reactor coal temperature, such as at least 800°F., during the continuous process.

In operation of the vessel 70, the sulphur enriched gas from the separator 56 is introduced, via the duct 58 into the reactor vessel 70 with steam being available from a source 84 to add moisture to the gas if and when needed. A continuous supply of granular coal from hopper 74 is passed into the reactor vessel 70 for reducing the sulphur dioxide and oxidizing the coal, while forming an ash product which is continuously removed from the reactor vessel 70 to the trough 80. The input flow of the coal from the supply hopper 74 and the flow of the ash product are regulated by the control valves 76 and 82, respectively, such that a relatively high proportion of the coal is utilized for the reduction of the sulphur dioxide. A sulphur output line 86 with an accompanying cooler 88 is connected at the bottom of reactor vessel 70 for removing the sulphur and/or hydrogen sulphide.

In accordance with the overall operation of the vapour generator, water is passed through the fin tube walls 14 and 16 and the sidewalls of the enclosure 12 as well as through a plurality of tube bundles 90 disposed in each fluidized bed in the compartments 22. Although, each tube bundle 90 is represented by only a single tube in the drawing, each tube bundle consists of a plurality of juxtapositioned tubes extending across the entire width of the enclosure 12. Although not shown in the drawing, the tube bundles 90 are connected by means of feeder tubes, downcomers, etc., in a manner to direct the water through the beds in a sequence determined by their respective connections. For example, the tube bundles 90 disposed in the lower two compartments 22 could be connected in series, with one of the tube bundles adapted to receive the water at a predetermined temperature, and the other tube bundle adapted to discharge the fluid to another stage of the system after it is heated further in the tube bundles. The other tube bundles 90 in the remaining compartments 22 could be individually connected to a steam turbine or adapted for use for reheating.

Although also not shown in the drawing, an additional series of tubes can be provided in the enclosure 12 that extend for the entire length thereof in a sepentine relationship to form a plurality of banks respectively disposed in the compartments 22 above each tube bundle 90 to enable the water passing into the system to be preheated before being passed through the fin tube walls and the tube bundles 90.

As a result of the foregoing, separate units for combusting the particles from the cyclone separator 42 and for regenerating the sorbent are eliminated since both of these functions are carried out in the housing 12.

Also, the use of high sulphur coal to reduce the sulphur dioxide to sulphur, which can be of a high degree of purity, in the vessel 70 provides a two-fold advantage, in that coal is much less expensive than natural gas and other reducing agents, while a use can be provided for the high sulphur coal which, if used in most other systems, causes severe air pollution problems. Also, a significant advantage afforded by this invention lies in the ability to carry out the reduction of the sulphur dioxide at much lower temperatures than heretofore had been possible. Thus, in accordance with this invention, sulphur dioxide, which is normally considered a pollutant, can be used to economically produce a useful product, such as sulphur.

Although this invention has been described in connection with a system in which the beds are fluidized by atmospheric air, it also is applicable to a system in which the beds are fluidized by pressurized air. As an example of the latter system, reference is made to U.S. Patent Specification No. 3,863,606.

WHAT WE CLAIM IS:—

1. An apparatus for generating heat comprising means defining at least one first zone for combusting a fuel in the presence of a sorbent for sulphur released during combustion of the fuel at conditions sufficient to sulphate the sorbent, means defining a second zone for receiving at least a portion of the sulphated sorbent from the first zone or zones and for combusting a fuel under conditions in which the sorbent is desulphated to form a sulphur enriched gas, means for transferring sulphated sorbent from the first zone or zones to the second zone, means for receiving the gas and continuously contacting the gas with burning granular coal to reduce at least a portion of the gas to sulphur, and means for transferring the gas from the second zone to the means for contacting the gas with burning coal.

2. An apparatus as claimed in Claim 1 comprising means for introducing steam to the sulphur enriched gas before contacting the gas with the burning granular coal.

3. An apparatus as claimed in Claim 1 or Claim 2 in which the fuel and the sorbent are in solid particulate form and means are provided for passing air through each of the chambers to fluidize each of the materials and promote the combustion of the fuel.

4. An apparatus as claimed in any preceding claim in which there are a plurality of first zones and all the zones are positioned vertically upon each other, at least some of the zones having walls which are adapted to transfer water to convert the water to steam by the heat generated in each chamber.

5. An apparatus as claimed in Claim 3 or Claim 4 in which in operation at least a portion of the fuel and sulphated sorbent is entrained in the air passing through the first zone or zones, and means are provided for separating fuel and sorbent from the air and directing the separated fuel and sorbent to the second zone.

6. An apparatus as claimed in any preceding claim comprising means for passing at least a portion of the desulphated sorbent from the second zone to the first zone or zones.

7. A method for burning sulphur containing fuels, comprising burning a sulphur containing fuel in at least one first combustion zone in association with a sorbent for the sulphur contained in the fuel at conditions whereby sulphur compounds produced in the combustion process react with the sorbent to sulphate the sorbent, removing at least a portion of the sulphated sorbent from the first combustion zone or zones and passing the sulphated sorbent into a second combustion zone, and burning fuel in the second combustion zone at conditions sufficient to desulphate the sorbent and form a sulphur enriched gas, removing the sulphur enriched gas from the second combustion zone, and contacting the sulphur enriched gas with burning granular coal to reduce at least a portion of the gas to sulphur.

8. A method as claimed in Claim 7 in which the sulphur enriched gas contains sulphur dioxide, and the sulphur dioxide is reduced to sulphur and hydrogen sulphide during contact with the granular coal.

9. A method as claimed in Claim 7 or Claim 8 comprising introducing steam to the sulphur enriched gas before contacting the sulphur enriched gas with the burning granular coal.

10. A method as claimed in any of Claims 7 to 9 in which the fuel and sorbent are in solid particulate form, and air is passed through each combustion zone to fluidize the fuel and sorbent and promote the combustion of the fuel.

11. A method as claimed in any of Claims 7 to 10 in which there are a plurality of first combustion zones and all the combustion zones are positioned vertically upon each other, and wherein water is passed in a heat exchange relation to the fuel in at least some of the combustion zones to convert the water to steam.

12. A method as claimed in Claim 10 or

Claim 11 in which at least a portion of the fuel and sulphated sorbent is entrained in the air passing through the first combustion zone or zones and the fuel and sorbent is separated from the air before introducing the fuel and sulphates sorbent to the second combustion zone.

13. A method as claimed in any of claims 7 to 12 in which at least a portion of the desulphated sorbent is passed from the second combustion zone to the first combustion zone or zones.

14. A method as claimed in any of claims 7 to 13 in which the sorbent comprises calcium oxide.

15. An apparatus substantially as herein described with reference to the accompanying drawing.

16. A method for burning sulphur containing fuels substantially as herein described with reference to the accompanying drawing.

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1470150 **COMPLETE SPECIFICATION**

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